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COVER: Robert Motherwell, *Open #29, In Orange with Charcoal Line*, polymer on canvas, 1968. (Color Courtesy Marlborough-Gerson Galleries.)

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COMPUTER SCULPTURE: Six Levels of Cybernetics

A PULSA environmental, light-and-sound installation at the Yale golf course, winter, 1969. Thirty strobe lights and linked speakers are triggered in constantly changing permutations and configurations by means of a computer program which includes both structured and random features.

ROBERT MALLARY

Sculpture is an extremely physical art dependent on the skilled manipulation of materials, tools and technical procedures for its realization. Historically the techniques of sculpture have reflected the technological level and character of the society in which the sculptor lived and worked. In the beginning he carved bone, wood or stone, or he modeled and fired clay. Later he developed the elaborate procedures of bronze casting—possibly the most advanced technology of ancient times. Today sculptors are increasingly turning to new materials and processes to provide them with a more contemporary technological base. They are using plastics, light arrays, strobe units, projectors, transducers and much else in creating their work. And they are beginning to use computers as well.

But the computer is more than a single item in an expanding inventory of art-and-technology

paraphernalia. All of these technologies are promising but the computer is *portentous*, because for the first time the sculptor has access to a tool which can be used not only for executing a work of art, but conceiving one as well. It has already been demonstrated that the computer can assist the sculptor to some degree; in the future it may, in effect, come to collaborate with him. (Some think that in time the computer may *compete* with the sculptor—even to the point of making him superfluous as a producer of art in the social and economic sense, if not as a human being with a continuing need for therapeutic self-expression and self-realization.)

Cybernetics is an interdisciplinary science, first proposed by Norbert Weiner, the brilliant MIT mathematician, in the late forties, linking together such topics as information theory, control systems, automation, artificial intelligence, computer

simulated intelligence and information processing. Cyberneticians generally make a distinction between *artificial* intelligence, in which a computer is programmed to perform logical or perceptual operations in the manner it can best perform them using its own natural machine "language," and *simulated* intelligence, in which the programmer uses the computer to imitate the ways he believes these operations take place inside the human head.

Composers were the first to sense the cybernetic potential of the computer and to grasp its implications for art. In 1955 Legaren A. Hiller and his associates at the University of Illinois began to use the ILLIAC computer to compose music. When computer graphics emerged about five years later it was almost immediately apparent that the computer, together with the plotter, could be used to make drawings of esthetic as

well as technical and scientific value. Use of the cathode ray tube (CRT display) further expanded these pictorial possibilities. In recent years computer graphic techniques have been applied to a variety of arts including choreography, abstract films and even to architecture. More recently they have been applied to sculpture as well.

The problem in applying the computer to sculpture is to program the computer to take in, manipulate and give back three-dimensional information which can be used for sculpture. This is a big order, in part because of the basic three-dimensionality of sculpture which compounds the intricacies of computer programming, in part because sculpture has recently come to take on so many forms, and in part because, through multimedia, its workings have become so complex.

In fact, as the PULSA group at Yale University has already demonstrated, one of the most valuable applications of the computer is to optimize the interactions within kinetic light-and-sound environmental systems. They are programming kinetic episodes of light and sound into set, reproducible scenarios using computer-made tape to control the output of the system. They are also reshuffling at random the sequence of the episodes while leaving their unit characteristics unchanged, thus introducing an element of unpredictability into the proceedings. Great variety and interest is achieved in their system through the use of transformation and over-lay variables in the programming, as well as through the use of relatively autonomous subsystems (phosphors, etc.), to generate endless patterns and permutations—achieving thereby a continuous morphology of spatial imagery-plus-sound.

According to Jack Burnham, in his book *Beyond Modern Sculpture*, kinetic art will eventually simulate living systems, sharing with them their autonomy and self-organizing characteristics as well as their ability to interact dynamically with their surroundings. It seems likely that in these complex processes, the computer will serve as both monitor and processor to structure the visual, auditory and possibly tactile output and insure optimum interest and esthetic quality. At least, options of this kind will be available if the kinetic sculptor should choose to avail himself of them.

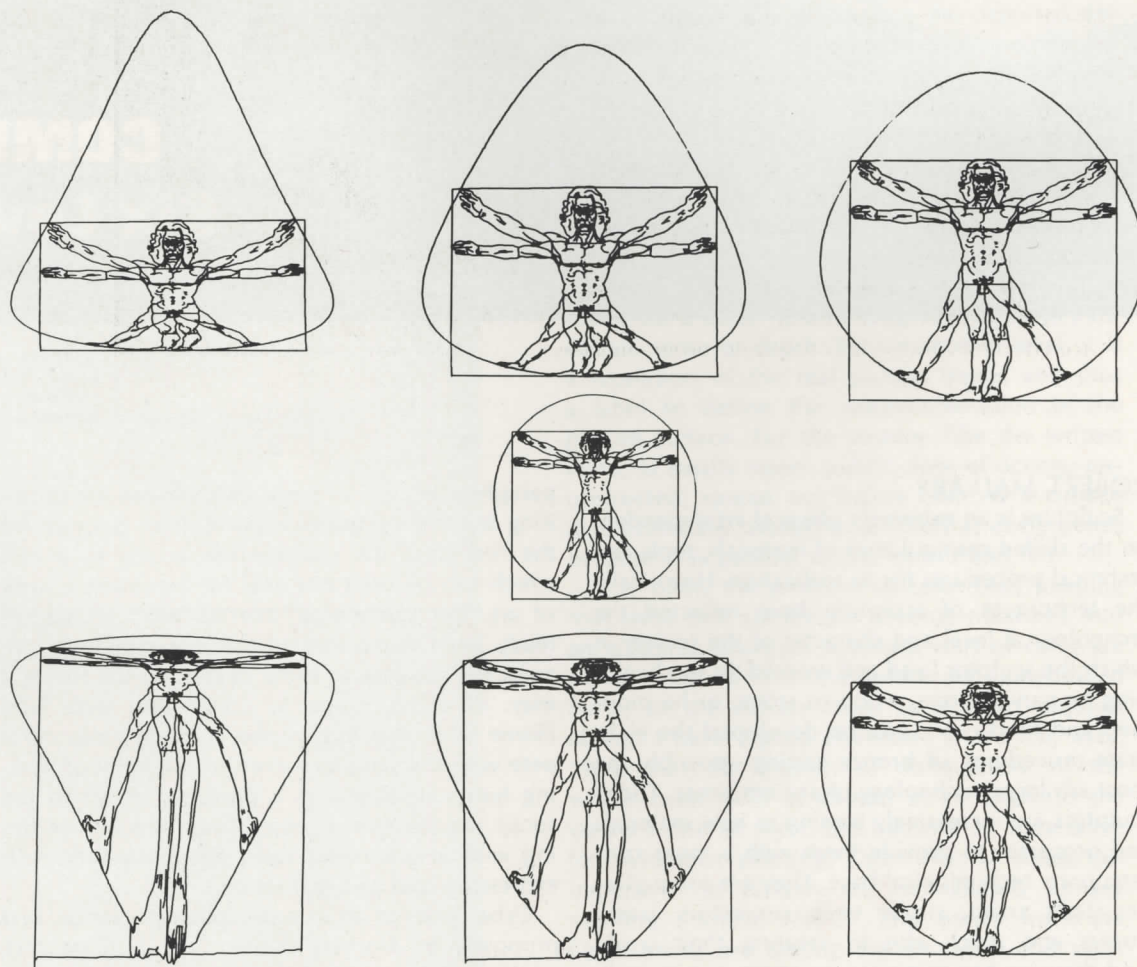
Electronics is a new field for sculptors and much that is now being done is embarrassingly crude and unsophisticated from both the technical and the esthetic point of view. Nonetheless, transductive intermedia setups and cybernetic-like feedback circuits are beginning to be applied so extensively, and on occasion so successfully, that we would be justified to think of another kind of art—perhaps the phrase *transductive art* could be used to denote this development. In technology a transducer is a device that receives energy from one system and transmits it, often in a different form, to another. In art the source energy would be a structured signal originating in one medium

which is translated into, and impresses its pattern upon, another medium.

For instance, if a succession of sounds is used to trigger a succession of light emissions this would be an example of transduction applied to kinetic art. And if the transductive process should dominate the multimedia situation it could be cited as a valid example of transductive art. This is all well and good and the possibilities are obvious: but if transduction is to provide the basis for a new kind of art there should be some criteria for evaluating the uses made of it. It is necessary to ask whether all transductive events are equally effective—or whether, for that matter, any of them are. In short, transduction itself should be examined more thoroughly.

As matters stand at present the effect of the one medium (for instance, sound) on the other medium (for instance, light) is at least problematical from the standpoint of the kind or degree of structuring which is actually communicated by the source medium and retained by the receptor medium. For instance, if the triggering sequence

of sounds is acknowledged to have an unquestionably musical character in the conventional sense of the word (as is somewhat uncertain given the random, aleatory processes involved in the music of John Cage and others), it remains to be demonstrated convincingly that the receptor light medium is thereby inevitably or automatically imbued with the structure of the musical source medium, or that it is imbued with at least some kind of corresponding, or equivalent, or parallel structure or that it is imbued with any kind of structure whatsoever. It is even more unlikely that the terminal output of kinetic light emissions can have any great degree of organization or coherency when the transductive signals have their source in the chaotic ambience of everyday, helter-skelter sound, which on occasion degenerates into the drone of a virtual "white noise." What these considerations suggest is that the computer can be expected to play a role in the syntax of intermedia translation, mediating the transductive transfer from the one source medium (sound) to the receptor medium (light) in order to achieve



a meaningful, structured transfer of information—assuming, of course, that the kinetic sculptor is interested in syntactic coherency, holding this to be essential to good art. In fact, I propose this issue of structured-versus-unstructured transduction as one to which all who are involved in any form of transductive art, or who are using transductive processes in multimedia light-and-sound environments, should give some thought.

* * *

So far the discussion has dealt with a single area of potential computer sculpture involvement—namely kinetic light-and-sound environments. But the computer will be used in a great variety of ways, in connection with many different kinds of sculpture, and new mediums will be developed to exploit in different ways the many-sided capabilities of the computer itself.

A serious contribution to computer sculpture has been made by Johann Severtson, now at Franconia College in New Hampshire, whose program utilizes computer graphic productions to specify both the 2-D shapes which go to make up his plastic and metal constructions as well as the screened graphics which are printed onto these 2-D surfaces. The program output also specifies where the “notches” are placed which are used to assemble the components. A possible limitation is that the computer at no point has a full three-dimensional description of the sculpture as a whole, nor does it provide as output computer graphic drawings of the total assembly, either in orthographic projection or in perspective—all of which is not to minimize Severtson's achievement in compiling this program. In fact, among its other merits, Severtson's program provides an excellent demonstration of the computer's unique permutation capabilities.

Michael Noll of the Bell Telephone Laboratory in New Jersey is primarily a scientist who, through his work with computer programs, has become much involved with computer art. He has worked in computer graphics, has programmed computer movies and also devised a cinematic choreography program. He has programmed linear stereo-drawings which, when seen in a stereoviewer, appear three-dimensional. In this instance there is no doubt but that the computer has generated complete three-dimensional information pertaining to the linear structures. What is lacking is provision for constructing real sculpture based on this information—but this is no lack if one allows that sculpture can be as well served by an illusory image as by a real one—at least if the illusion is made sufficiently convincing. For that matter, it is my conviction that the “ultimate” medium for kinetic sculpture will, indeed, be based on some fantastically sophisticated system of three-dimensional projection.¹ However, this system will not be based on stereoscopic principles, which are inherently and irremediably defective no matter how clever the system making use of them.

Alfred Duca, working with IBM programmers, has made a large spherical sculpture carved directly out of steel by a tape-driven machine tool. Nor is there the least doubt in this instance that the computer has been given data with which to compile and specify a comprehensive, three-dimensional description of the sculptural form; moreover, it is certain that without the program, the computer and the milling machine the sculpture would never have been made at all—though without these it possibly *could* have been made at great expense and difficulty. It would seem that what this program lacks is permutation capabilities, though I also suspect the program could be expanded without too much difficulty to include these.

TRAN2, the computer sculpture program which has occupied me and my student associates for the last eighteen months or so, is still at the crawling stage in terms of programming and hardware sophistication, but even at that it has opened up several possibilities for sculpture which were



An engineer designing at the console of a computer graphic CRT display. (Photo courtesy Douglas Aircraft Company, Inc., Santa Monica, Calif.)

not available in the past. It can also be said in its favor that it embodies, even if only in skeletal form, the essential requirements of an authentic computer sculpture program. It provides several modes of data input; it gives the computer a full, three-dimensional description of the material it must work with; it provides ways to process, modify and reshape the form description input material; and it provides several kinds of graphic output usable for evaluating the computer's productions and for physically constructing an actual sculpture if the drawings are sufficiently promising.

If a computer is to make sculpture it must be given either a comprehensive numerical descrip-

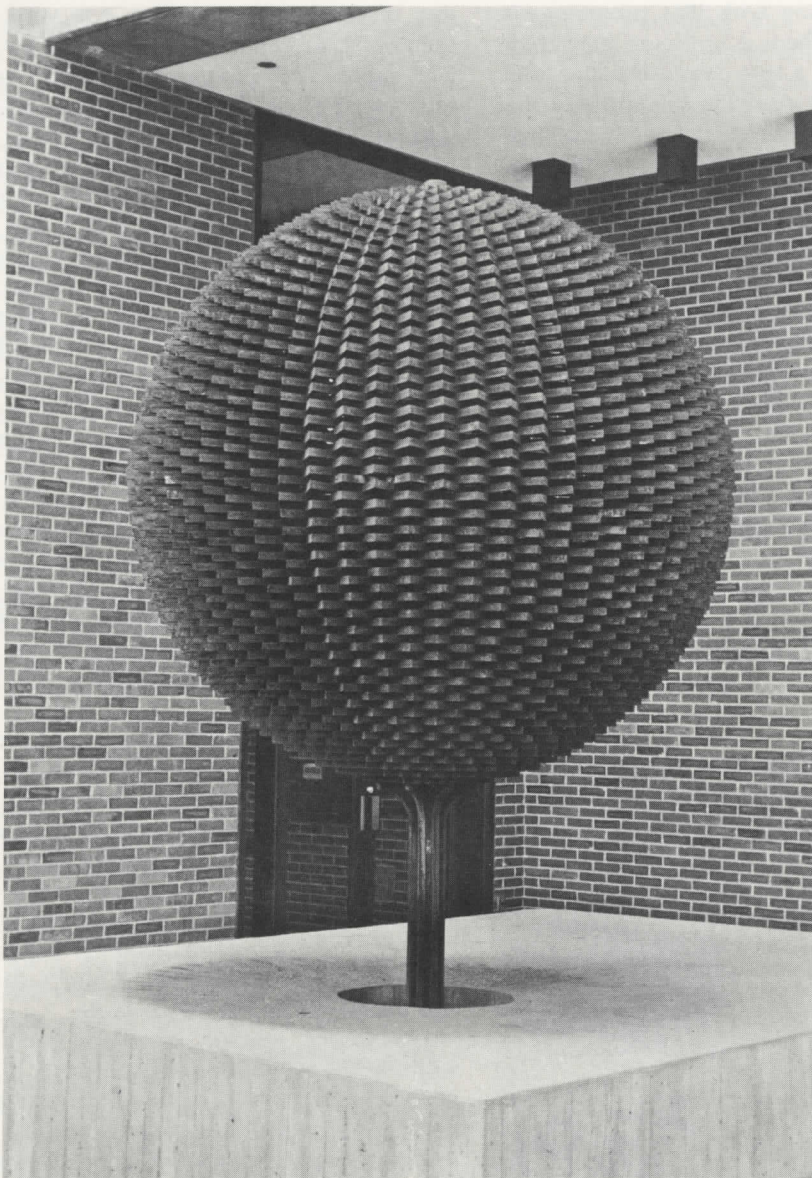
tion of the basic material it is to work with, or the means to generate this material for itself. In fact, our TRAN2 program does both, using contour “slicing” as the basic method of form description and form generation. In effect, the form is sliced—much as an apple or a chunk of baloney might be sliced—into a series of thin cross sections of equal thickness which can then be graphed, digitized and encoded on computer punch cards. It is also essential that each of the slices has an axis point to position it relative to all the other slices on the vertical axis. It is by means of this “stacking” of two-dimensional data that the program converts standard computer graphic capabilities to the requirements of three-dimensional form description.

TRAN2 uses between forty-eight and a hundred contours. This is not enough for a smooth, continuous definition of the form (*i.e.*, without a visible demarcation, or “step,” between one contour and the next) but it is a practical minimum considering the limited capacity of the Amherst College IBM 1130 computer for which TRAN2 is programmed.

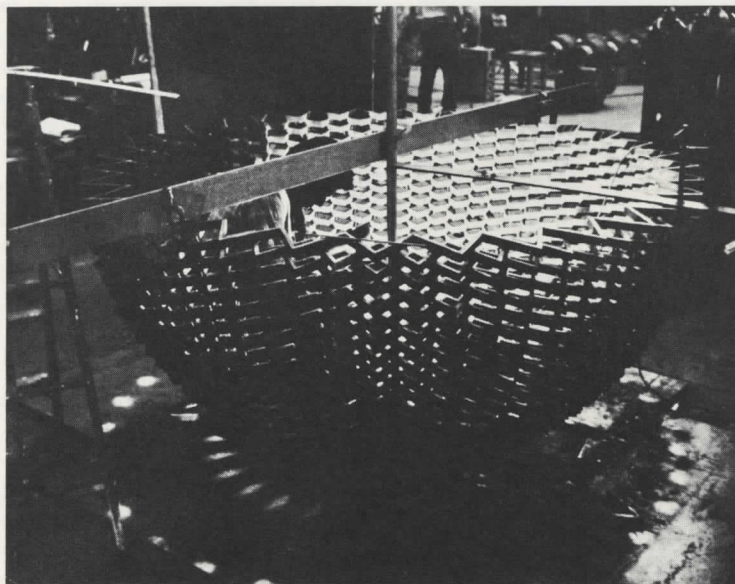
In its present state TRAN2 uses two methods of form description input. The first requires an antecedent handmade prototype form which must be traced three-dimensionally with a “contour grapher” of our design. The grapher has a moving probe which traces off the contours at regular intervals along the vertical axis of the prototype form and transfers them to graph paper. The traced contours are then digitized with X and Y coordinates and transferred to the punch cards.

The second method is called “profile input” with PROSA as the program call-word. In this case no prototype form is required because the computer itself calculates and constructs the form using as data a small store of graphed profile drawings. Eight profiles are stored at a time, though only four are needed to generate a complete form (and only two are needed if the contour sections are generated entirely from circles). By typing in selected TRAN2 subroutines such as ELIPS, OVAL 1, OVAL 2, SUPER, and QUAD, it is possible to generate a special kind of sculptural form for which all the cross sections, at all levels along the vertical axis, can be specified as perfect circles, ellipses, super-ellipses or as ovals of various kinds. QUAD calculates contour sections based on quadrants from four different ellipses and was used in our first series of TRAN2 sculptures, QUAD I, QUAD II and QUAD III.

The computer, once it has the form description data it needs, is converted, in effect, into a sculptural modeling and shaping tool. This is accomplished by calling up one or more of the transformation subroutines such as EXPND, ROTES, MOVES, and ASMTL. These generate permutations on the input data, applying a variety of mathematical functions similar to those used by Charles Csuri of Ohio State University in connection with his well-known computer transformations of a



Alfred M. Duca, untitled sculpture. The work was carved directly, out of steel, by a tape-driven machine tool.



Duca sculpture in construction.

drawing by Leonardo da Vinci.²

The output subroutines determine the kind of drawing the computer is to make. PERSP specifies a perspective drawing, the sculptor typing in the angle of vision he wants—at, above, or below eye level. He also specifies the view he wishes, which can be any of 360 degrees around the form. By instructing the plotter to make a series of drawings at, say, fifteen degree increments he in effect revolves the form and obtains an idea of what it would look like if it were to be fabricated.

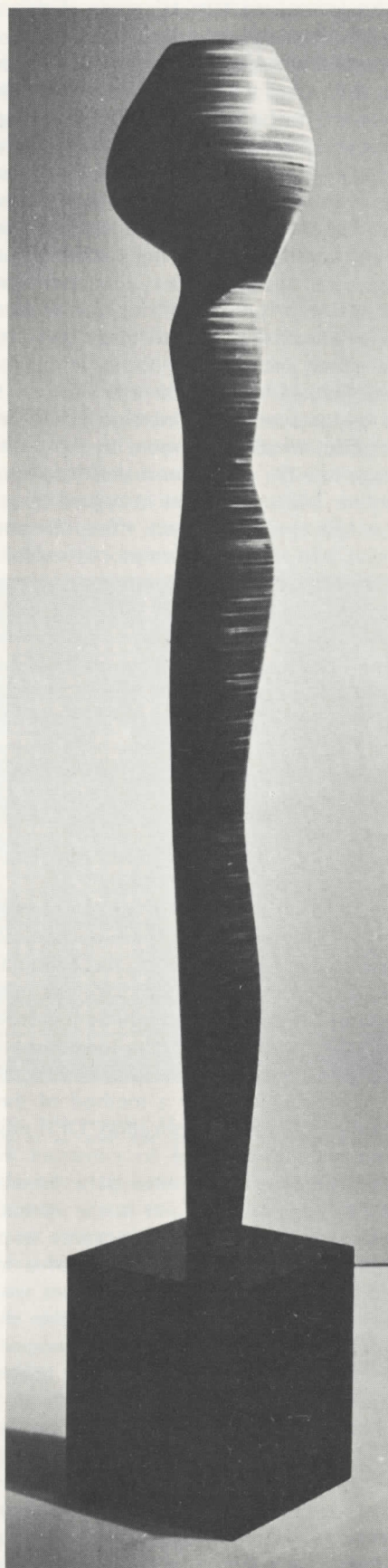
CONTR calls up a plot of the entire set of contour cross sections as orthographic projections. Each of the contours includes both a center point and a reference mark to orient the contours in the proper position one to the other. The entire set of contours is photographed as an 8 x 10 inch positive transparency, inserted into an overhead projector, projected onto some appropriate material such as wood or plastic, and traced. The set of traced contours is then cut out, the center holes are drilled, and the contours are stacked over a metal rod. Finally, the contours are glued, laminated together under pressure, ground down to remove the "steps," and smoothed and polished. These, of course, are manual operations at the handicraft level, but in principle, inasmuch as the computer has generated all the essential three-dimensional information, the sculpture could also be made using a numerically controlled milling machine.

TRAN2 is slow in its operations when measured against the incredible speeds of a large computer. It is also limited in that it can handle only solid, volumetric forms oriented around a central axis; concavities are possible but undercuts are ruled out (in fact, it will be some time before the computer can be applied in a practical way to planar, linear, or open-form sculpture). This means that TRAN2 must not only be upgraded from the plotter to the CRT display but must acquire its own console and special instrumentation, particularly if there is to be a dynamic and productive interaction in real-time between the sculptor and the computer.

It is not clear at this point whether such a system will be best served by a small, monotypic "dedicated" computer—perhaps an analog, or a digital/analog device—or by a remote console and teletype setup linked on a time-sharing basis with a large central processor. Possibly a combination of the two would be the best arrangement. Stereo displays, and possibly a holographic display system, should eventually increase the clarity, precision and overall efficiency of computer graphic interactive displays for communicating three-dimensional form information.

I am going to close this part of the discussion with a listing of the main capabilities of a truly advanced computer sculpture system. My intent is not to make a prediction but to give an idea of the direction in which TRAN2, or any other program of a similar character, must move if there is

to be a fully interactive, synergistic man-machine relationship. Such a system would allow the sculptor, among other things, to perform the following operations: (1) Generate single or multiple forms on the display—combining, interpenetrating and linking them with entire freedom and precision. (2) Alter the sizes and shapes of the forms by means of an extensive repertoire of mathematical transformation functions, applying these to the forms either one-by-one or as combinatorial aggregates and units. (3) Introduce localized and minor transformations limited to small portions of the forms, using for this purpose specialized transformation “templates” and perhaps a super-sophisticated variant of the light pen. (4) Apply negative, subtractive form take-away procedures to carve out concavities and perforations. (5) Generate negative forms and surfaces from positive ones, as in conventional mold making techniques. (6) Cut the form in half, turn each half inside out and rejoin the two halves. (7) Apply surface rounding and blending procedures to merge discrete forms and surfaces into smooth, homogenous continuities. (8) Zoom (enlarge) the form, visually penetrate it as if to see it from the inside with all the convexities and concavities reversed. (9) Derive a third form (C) from two already given forms (A) and (B) by calculating a mathematical “mean” between forms (A) and (B). (10) Perform topological, mathematical “tricks” such as bending a form back on itself, through itself, or around itself—or by tying it into a knot or turning it inside out. (11) Switch to a variety of graphic modes, such as outline drawings, transparent wire drawings, wire drawings with the hidden lines removed, light-and-shadow simulations (including the form as seen under a wide range of simulated mobile lighting conditions). (12) Provide full color capability to exploit coloristic values for their own sake as well as for the graphic definition and articulation of three-dimensional form. (13) Provide a high “verisimilitude coefficient” permitting representations of persons and objects to be used as such (*i.e.*, as convincing replications) or for subjecting to the system’s full range of transformation capabilities. (14) Through the use of a playback capability recall onto the display the work-in-progress at any previous stage of its development. (15) Use the preceding capability for its iterative, “branching” possibilities (*i.e.*, from any given branch point alternative solutions to the sculptural problem can be tried, stored, compared and evaluated). (16) Provide scope arrays so that the evolving, mutating forms can be viewed simultaneously from a variety of angles, or at successive stages, or in a variety of permutations. (17) Enlarge the scope to provide a virtual cinematographic experience, or enlarge and position the array of scopes to provide an experience of total image envelopment. (18) Provide central repositories, or libraries, of programs, as well as hardware facilities, to be leased and used by the sculptor at his end of the hookup (*i.e.*, in his studio



QUAD III — A TRAN2 computer sculpture in laminated veneer by Robert Mallary. On the basis of an input of four profiles, and using segments from four ellipses, the computer has filled out each of 48 contour “slices” and assembled them on a common vertical axis. It has subjected them to a series of transformation procedures resulting in three variations on the same input . . .

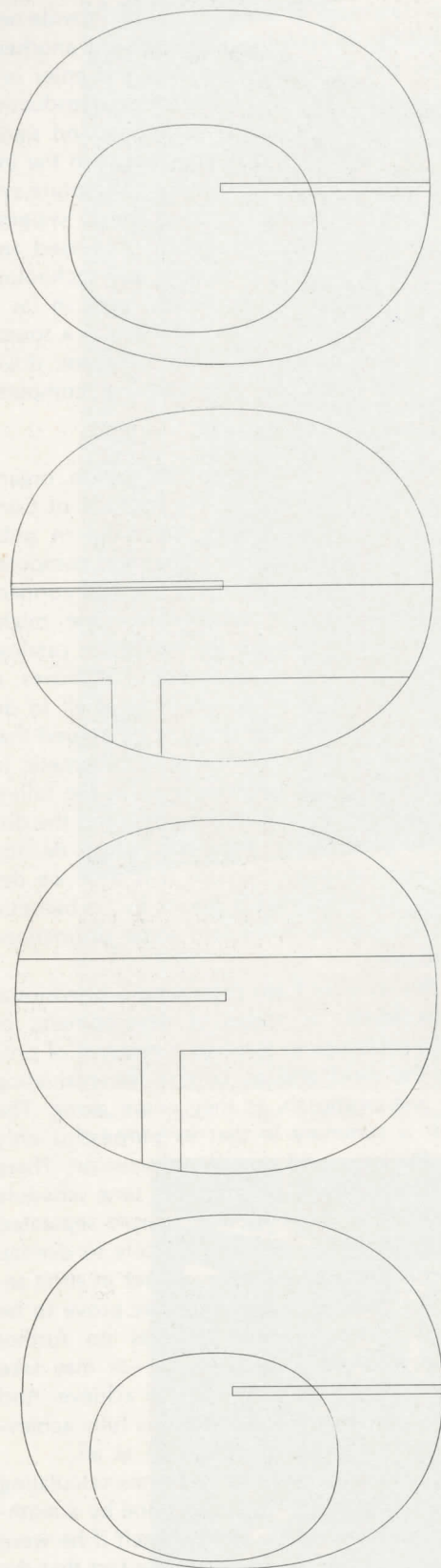
or in his classroom or laboratory). (19) Provide network facilities so sculptors can share one another’s programs and hardware resources and enter into collaborative interactions. (20) Provide transductive linkups with a wide variety of energy and signal sources for interactive dialogues between the impinging “stimuli” and the computer sculpture system. Use particular and bounded energy systems, such as human beings, as well as dispersed and ambient systems, such as crowds and technological and ecological forces. Finally, plug in (as it were) the total electronic environment as a source of transductive signals to shape, structure, drive, catalyze, and energize the ongoing computer sculpture.

* * *

The “Cybernetic Serendipity” exhibition, organized last year in London by the Institute of Contemporary Art, while hugely successful in publicizing and dramatizing electronic and computer art, was less helpful in clarifying the real connection between art and cybernetics. One might assume, thumbing through the exhibition catalog, that almost anything is cybernetic if it moves, if it is robot-like, or if it has anything at all to do with the computer. While it might be argued that any application of the computer is cybernetic in some sense, it is not necessarily so in the fullest sense, or even in a substantial sense—and the distinction is particularly important when dealing with art and creativity. Perhaps it is time we define more precisely what is meant by “cybernetic art” and attempt to formulate some distinctions and standards.

With this in view I am proposing a provisional list of six levels, or stages of development, of cybernetic sculpture to serve as a measure of progress in the field and as criteria for evaluating projects and proposals as they come along. The treatment is summary in that its purpose is only to focus the issue and stimulate discussion. There is no precise, or even approximate, time schedule implied, nor can the stages be sharply separated one from the other; they are as likely to overlap and co-exist as to follow one another in strict sequence. For example, stage four may prove to be surprisingly close in time—perhaps no further away than the turn of the century—or may take fifty or a hundred years or more to achieve. And there is no certainty that stage five is fully achievable or that stage six is achievable at all.

At stage one the computer performs calculating chores that in principle could be done by a mathematician, or even by the artist himself if he were trained and had the patience. But the fact that the machine is available to do this tedious work with such incredible speed and precision makes all the difference in the world in terms of the new possibilities for sculpture which are opened up even at this primitive level of cybernation. For example, it has already been shown that by using the TRAN2 profile subroutines it is possible to generate a special kind of form with geometrically



Four permutations of a super-ellipse from Johann Severtson's computer sculpture program. The computer-drawn graphics are used as patterns to cut out the shapes of plexiglass which comprise the sculptures and as material to screen onto the plastic surfaces.

uniform cross sections. No claims are made as to the esthetic value of a sculpture of this kind—only that this capability exists for whatever its value may prove to be, plus other untested possibilities which have yet to be programmed. For example, varied and complex three-dimensional systems of symmetries are a natural for the computer, and it would also be easy for the computer to specify how colors could be used to articulate the sub-system configurations comprising such structures.

At stage one the computer generates varied presentations and "proposals" for the sculptor's consideration, and the rate of image generation might be either fast or slow. While it might be contended that an increase in efficiency in this regard is tantamount to an increase in the level of cybernation, what seems more to the point is that at stage one the computer makes its offerings with absolute indiscrimination in regard to quality—i.e., it fails to say, in effect: "Yes, this one—no, not that." In short, the sculptor is exploiting the awesome capacity of the computer as a super-calculating machine in the old-fashioned mechanistic sense, but not as an electronic embodiment of creative intelligence. Yet, even at this stage, when the sculptor makes all the crucial decisions, when his interaction with the machine is limited, and when his program is cybernetic only in a rudimentary sense—even at this stage the relationship between the sculptor and his computer is synergistic, or symbiotic, in that each depends on the other to do his "thing" and both together do something that neither could do alone.

At stage two the computer is an *indispensable* component in an electronic, electromechanical or electro-optical device relevant to the production of sculpture or to the working of a kinetic, multimedia system. For instance, it might be involved in sorting out the myriad visual data located on the receding planes of an object in space—doing this, possibly, in connection with a method of three-dimensional projection or replication. Or it might, also in the future, be used to construct from scratch the complex interference patterns which make up a hologram. The point is, the operation under consideration would be impossible to perform given the full-time brain power of a regiment of mathematicians. These operations would be impossible, not only because of the sheer mass of data to be handled but also because of the close and complex interconnections between the computer and the other components of the system—not to mention the real-time demands which can make essential information useless if it is even milliseconds tardy in being made available to the system. In such a system, even though the computer is clearly indispensable and integral to the design, the situation in regard to the level of cybernation is still not fundamentally different from that of stage one. While performing its exacting chores with superb efficiency, the computer still does not have a controlling function nor is it making decisions crucial to the operations of

a flexible, versatile and virtually self-propelled system.

A word must be said at this point regarding randomness, a computer capability which, for many people, particularly in the arts, is virtually synonymous with cybernetics itself. This notion, of course, is at best an over-simplification and at worst a gross confusion. The use of stochastic techniques to generate control decisions and permutations is low-order cybernation if unattended by filtering, selecting, discriminating and otherwise structuring features in the program. A living, intelligent being may at times behave in ways which are seemingly random and unpredictable, but it does not follow that a device, or a work of kinetic art, which can be programmed to behave unpredictably is thereby cybernetic. Put in other terms, randomness is not sufficient for a cybernetic system though it is likely to be an important feature of such a system.³

Therefore, stochastic capabilities should certainly be incorporated into a computer sculpture system at least by stage two. Randomness can be particularly important in computer art precisely because it is *not* a fixed and absolute thing; in other words, there are kinds and degrees of randomness and there are possibilities for intermixing the random features of a program with its more structured aspects, using their interactions as a mode of control and as a kind of dialogue—a "tension"—within the program.

Stage three requires that the computer, within limits sharply defined by the programmer, make not only routine discriminations but decide on alternative courses of action governing the whole system. But these decisions are made within guidelines sharply defined by the program. The instructions given the computer might be something on this order: if A, do B, but only if C has not first been determined by D, and then only if a certain quantity of E exceeds that of F by such-and-such a proportion, and so on. For this kind of programming the programmer must know precisely what the computer has to do; either it is instructed exactly as to how it is to go about the job with no false starts, fumbings or blind alleys allowed, or a situation must be set up which enables the computer to make sound decisions over the long pull on a statistical basis, while leaving to the sculptor the final decision as to which of the computer's productions have merit and are usable.

The implications of all this in terms of the evolution of a true "science of art" should be clear. Because programming requires logic, precision, and powers of analysis, as well as a thorough knowledge of the subject matter and a clear idea of the goals of the program, at all levels of cybernetic sculpture the technical developments in programming and hardware will proceed hand-in-glove with a steady increase in the theoretical knowledge of art, as distinct from the intuitive and pragmatic procedures which have characterized the creative process up to now.

At stage three there are various options open to the sculptor, all of which are cybernetic in various ways and degrees. He may use the computer interactively and synergistically, encouraging it to make its "own" offerings and proposals and to make many of the form decisions for itself. But at every step of the way, the sculptor reserves a power of veto over the computer and monopolizes the crucial decisions, including the terminal ones which determine when the work has been completed and is acceptable. He scrutinizes the succession of computer offerings—accepting, rejecting and modifying them while prodding and coaching it to move in the right direction. These control-and-response capabilities are more or less of the kind included in the list of twenty items already cited; taken together they exemplify computer-aided sculpture in the fullest sense of the word, as distinct from computer-generated sculpture, to be defined next.

The sculptor's other option is to use the machine, not interactively as just described, but by programming it to move in a set way over a prescribed route and test for itself the succession of permutations it generates. In this case the computer follows a scenario of input instructions and proceeds on the basis of a stored program of guidelines and criteria for making sound decisions. In this way the odds are stacked in favor of potentially acceptable solutions at the expense of the not-so-acceptable, and the unacceptable ones are either revised or rejected outright. The sculptor, once he has pushed the "program start" button, can either read a newspaper, monitor the proceedings, or leave the scene of action entirely, having called for a tape which he can later use for an off-line playback and study at the display.

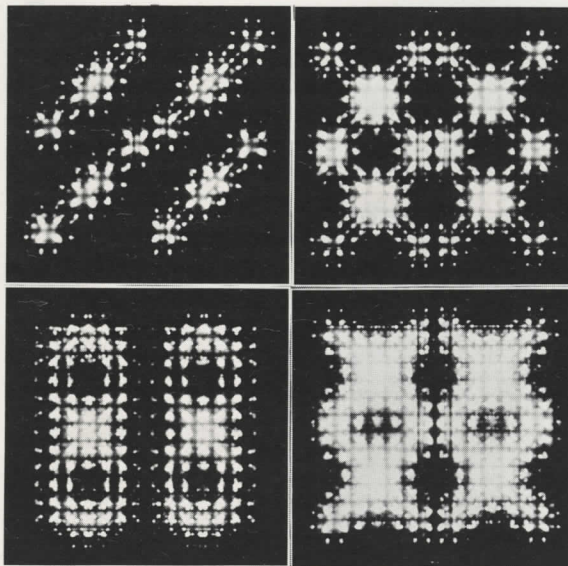
This is computer generated sculpture in the proper sense of the word, though the difference between this and computer-aided sculpture has more to do with the kind rather than the degree of cybernation. Nor are the two modes mutually exclusive: it can be expected that the process of making computer sculpture will in practice combine features of both. At this point computer sculpture finally will have moved abreast of where computer music is now—which, for that matter, entered this third phase almost at its inception in 1955.

At stage four the computer, seemingly proceeding almost entirely on its own, begins to make decisions and generate productions that even the sculptor cannot anticipate. At this level all the contingencies generated by the ongoing program have not been defined in advance—in fact, the program itself manufactures contingencies and instabilities and then of itself proceeds to resolve them in a way analogous to the workings of stress and homeostasis in living organisms. It generates unpredictable productions, not only out of the random interventions which dislocate and violate, as it were, the structured features of the program, but out of the total character of the

system itself, given its extreme complexity and nearly life-like virtuosity. At this level the computer is programmed to modify and elaborate its own program, doing this on the basis of its immediate, give-and-take interactions with the sculptor as well as on the basis of past encounters and sessions which it "remembers." At the same time the computer is likely to be much involved in mediating and structuring transductive intermedia signals and responding to environmental interventions as well.

Also at this stage there is a continuing redefinition of the role of the sculptor in respect to the computer, which is alternately his slave, collaborator or a virtual surrogate for himself. He operates the machine, monitors it, or leaves it to its own resources. In respect to the machine he is active and passive, creator and consumer, participant and spectator, artist and critic.

At stage four the computer's heuristic capabilities enable it to remember the crucial form de-



Four states from *Sequence II* as produced by Electronic Light Modulator III by John Roy, University of Massachusetts.

cisions and preferences of the sculptor, while checking these against his previous performances or against more objective "consensus" (i.e., collectively arrived at) criteria filed away in the stored program. A heuristic program of this sort can be thought of as embodying the sculptor's long-term preferences, style and personality, or at least his personality as an artist, and opens up the possibility of the posthumous production of art—i.e., after the sculptor's death, the computer, loaded with a lifetime of accumulated programming, at the flick of a switch churns out works "in the manner of."

Stage four is the optimum creative situation, taking into consideration both human and technological imperatives and the need, both from the individual and social point of view, of achieving a healthy balance between the two. At this stage the man and the machine together, in achieving a level of performance and productivity beyond that

of either alone, will have fully realized the synergistic potential.

I do not propose to deal to any extent with either stage five or six because both involve an ascent into the heady stratosphere of science fiction—which we have learned, however, not to discount. Predictions regarding the remote future are apt to miss the mark because they are beyond the range of extrapolation based on present conditions and because it is impossible to foresee developments that are so radically novel as to exceed the powers of the contemporary imagination.

At stage five the computer, while not alive in any organic sense, might just as well be, if it were to be judged solely on the basis of its capabilities and performances—which are so superlative that the sculptor, like a child, can only get in the way. He is no longer needed in the synergistic collaboration because the computer has arrogated to itself both human and machine functions, doing both in a superior way. The computer is a virtually autonomous being, even if it should not move about robot-like and even if the sculptor should still have the ultimate recourse of being able to "pull out the plug."

At stage six the sculptor, if the word by that time has not long since been divested of its current meaning or discarded entirely, will probably not be able to pull out the plug. Perhaps the machine will have achieved some kind of organic, self-replicating mode of existence, or will have evolved into a state of pure, disembodied energy or spirit—something of the sort that Jack Burnham and a few way-out computer theorists seem to have in mind. But in terms of our present requirements such speculation is almost irrelevant; it offers little counsel in regard to more urgent considerations—say, the transition from stage one to stage two, or from stage two to stage three, which, taken together, are a sufficient challenge to keep sculptors, programmers and instrumentation designers busy for some time to come. ■

1. My rather stiff criteria for this "ultimate" system of 3-D projection is as follows: at twenty or thirty feet the spectator cannot tell the difference between an actual object or scene and a projected one.
2. For example, EXPND is used either to stretch or compress a contour section on the X or the Y axis or on both. If 1.0 is typed for X and 1.0 for Y there is no change in the contour or in the assembled form. But if .5 is typed for X and 2.0 for Y the form is halved on X and doubled on Y. Incremental changes can also be specified as well as incremental rotations (also used in *QUAD III*), the effect of the latter being to twist the form by specified degrees. The majority of the transformation subroutines are based on arithmetical increments and functions, but logarithmic transformations are also available and are more diverse and interesting. In fact, we have only begun to explore the range and versatility of these and other transformations, either in the sense of improving and extending TRAN2 with additional transformation capabilities or of exhaustively testing those already programmed.
3. Here is an example of this kind of confusion: "Inasmuch as these phenomena [flickering lights, etc.] are constantly variable, the reactions are likewise ever changing and unpredictable, which endows the mechanism with an almost organic life and sensitivity." (Nicolas Schöffer, Editions du Griffon, Neuchâtel, Switzerland, 1963, p. 50.)
4. Dr. Philips Morrison, Professor of Physics at MIT, writing in the January, 1969 issue of the *Technology Review*, has this to say: "The third kind [of biology] will deal with computer-based life, which will have such properties that all of us will be taxed to distinguish them from the thought of man. Turing had this dream and I think we will not pass the turn of the century before we realize it in some degree."